AD-A013 812

DETERMINATION OF THE ELECTRICAL PROPERTIES OF M9 PROPELLANT

Charles T. Davey

Franklin Institute Research Laboratories

Prepared for:

Picatinny Arsenal

May 1975

p1-126-1 DC

241032

ADA013812

Technical Report

Final Report
F-C3854

DETERMINATION OF THE ELECTRICAL PROPERTIES OF M9 PROPELLANT

by

Charles T. Davey

May 1975

Prepared for

PICATINNY ARSENAL

Contract DAAA21-74-C-0317

THE FRANKLIN INSTITUTE RESEARCH LABORATORIES
THE BENJAMIN FRANKLIN PARKWAY • PHILADELPHIA PENNSYLVANIA 19103

63

Final Report F-C3854
"Determination of the Electrical Properties of M-9 Propellant" by
Charles T. Davey, Physical and Life Sciences Dept., Applied Physics Laboratory - P. F. Mohrbach, Manager
Picatinny Arsenal - U.S. Army Contract DAA21-74-C0317

W. B. Ligett
Vice President and Director

ABSTRACT

Electrical properties of M-9 propellant were examined with varying temperature, humidity, density, particle size and electrical excitation. Main interest was in potential electrostatic problems in processing, handling and loading this propellant.

Conductivity, dielectric constant, breakdown strength, and sensitivity were studied.

The graphited propellant is a semiconductor. Resistance goes down with increasing humidity, temperature and mechanical loading. Dielectric constant for the bulk propellant is about unity across the temperature range but may be as high as 1.1 or so.

The propellant causes electrostatic charge generation in movement, collection and handling which under low humidity conditions can be appreciable; however, the conductive properties of the propellant prevent accumulation of electrical charge when adequate conductive paths are provided within the container (grounding).

Sensitivity of the M-9 was investigated by applying short pulses of electrical energy (up to 35,000 volts at several hundred amperes). Energy measurements were made by analysis of calibrated current and voltage waveforms made during firing. Simultaneous 1-microsecond photographs were made of the propellant grain. Exposures at or above 12.5 Kv caused erosion of the graphite coating and polishing of the grains. Tendency was for the propellant to ignite during pulse application, and then, after the pulse was removed to extinguish for energy inputs up to several joules. Propellant that was ground in a pepper mill exploded repeatedly, but with 3 to 4 joules of energy input.

An inspection was made of the Indiana Army Ammunition plant. Procedures are such as to limit electrostatic build up in most operations. While some static generation is definitely occurring, it is felt that the magnitudes necessary to cause initiation of the propellants studied here is highly improbable.

Preceding page blank i-ii

Areas of doubt exist mainly in two areas: (1) propellant dusts, and (2) gaseous products. Dusts were not observed in the plant and the tough, plastic-like nature of the propellant would probably resist dusting, but further investigation, even negative results, would be productive. Gases and vapor are present. These should be examined for static sensitivity and ability to propagate a reaction in the propellant.

ACKNOWLEDGEMENTS

Cooperation and guidance of Picatinny Arsenal personnel is gratefully acknowledged. T. Warshall, F. Correll, and D. Seeger all provided significant input and guidance to this program. Personnel of ICC American Plant Operating Contractors at IAPP were most cooperative during our inspection trip.

Ramie H. Thompson developed the high voltage generators and ancillary equipment to provide high-energy short pulses and helped in getting this together. Walt Cipkins provided pulse testing and Joe Heffron much of the photography that was used in this program.

CONTENTS

CONTENTS (cont)

TABLES

FIGURES

1. INTRODUCTION

1.1 GENERAL

Explosives are intended to do work. The kind of work wanted determines what explosive materials are to be used. High explosives may be used to shatter, burn and cut or crush. Low explosives, like M-9 propellant, are used to move a shell efficiently; however, under certain circumstances materials like M-9 can detonate.

With all stored energy or energy sources, there is the possibility of release of energy at an inopportune time. Such is generally the case with lightning, hurricanes, tornados and other natural phenomena. Electricity, compressed gases and moving machinery suffer from the same fate at times.

With explosive chemical reactions, input requirements to initiate the reaction are sometimes well defined and in other instances are not defined at all. Generally, explosive operations are carried out in a safe manner. To conduct them otherwise is to invite disaster. Unwanted reactions have happened in plants using M-9 propellant. A suspect cause of such reaction was static electricity, and that suspicion is the motivating force for the scientific investigation reported here.

Measurements on plant operations were made and reported earlier.(1)*

1.2 PLAN OF RESEARCH

The basis for this investigation was a desire to know more concerning the electrical properties of M-9 propellant. The matrix of Figure 1-1 represents the essential measurements and conditions desired as a part of this work.

*Please refer to bibliography at the end of this report for reference.

MEASUREMENTS \ CONDITIONS	(A) Humidity	(B) Density	(C) Temperature	(D) Particulate Size	(E) Frequency	(F) Electrical Preconditioning
1. Conductivity						
2. Dielectric Constant						
3. Hysteresis						
4. Breakdown Strength						
5. Charge Relaxation						
6. Sensitivity to Initiation						

Figure 1-1. Evaluation Matrix for M-9 Propellant

The plan was initiated because many of the indicated measurements and conditions had previously been unexplored. During the course of the program changes were made in emphasis either as a result of preliminary experiments or as a result of reasoning. These changes were made in accord with the project officer and did not change the contract scope.

Sensitivity to initiation (measurement 6) was removed from the matrix and treated separately. Conditions of frequency (E) and electrical preconditioning (F) were removed for possible consideration at a later time.

One important part of the plan was an on-site inspection of a plant in the process of producing components used in ammunition. This inspection was carried out in the first quarter of the program. A trip report indicating the observations on the site visit is appended (Appendix A).

1.3 CHARACTERISTICS OF M-9 PROPELLANT

M-9 propellant is composed of 57.75% nitrocellulose (13.25% nitrogen), 40% nitroglycerine, 1.5% potassium nitrate and 0.75% diphenylamine.[(2)] Nitrocellulose may be detonated with the same shocking power as TNT as determined from the crushed sand test.

Nitroglycerine, like nitrocellulose will detonate. Combination of these main ingredients results in a product (M-9 propellant) which also will detonate.[(3)] A three-inch deep limit has been suggested in the use of this propellant.

Two grain sizes were considered in the study, .023 web and .006 web. Each was graphited.

Examination of the propellant grains showed the graphite to be relatively thin. The propellant itself was an opalescent white, translucent, tough and plastic-like. The material could readily be punched with a pin point. The propellant flowed as the point punctured the grain. A sharp blade could shave small slivers of the propellant grain.

2. EXPERIMENTAL EFFORT

2.1 PRELIMINARY EXPERIMENTS

During the formulation of plans and before specific formal experiments were performed, some preliminary experiments were made to allow for better planning and to gain insight into the electrical performance of the propellant.

a. *Resistance Data.* Propellant was placed in a glass tube and two electrodes were introduced into the tube at either end. Propellant was placed between the electrode and the resistance measured remotely using an ohmmeter. Dimensions of the electrodes, tubing and propellant were recorded.

Findings of these experiments were:

1. Both grain sizes of the propellant were conductive.
2. Resistivity for the .006-web propellant was approximately 3.28×10^6 ohm cm.

b. *Effect of Increased Power and Current.* The same experimental fixture was connected to a power supply in which current and voltage could be monitored on meters. Current application was begun at a low level, several milliamperes, and then elevated.

Findings were as follows:

1. The propellant was capable of withstanding relatively high currents (20 milliamperes) without initiating a reaction.
2. Activation of propellant samples at 20 milliamperes resulted in step increases in resistances--possibly from graphite path burn out.
3. Compression of propellant samples in the fixture resulted in decreased resistance.

c. *Power Handling Capacity.* A single gr[illegible] of .023 web propellant was connected on each of its cylindrical ends by means of electrically conductive clip leads. A power supply was connected so that its output was impressed across the single grain. The voltage was increased until a spark or arc was noted. The voltage was allowed to remain impressed across the single grain until arcing stopped at which time the circuit was ess[illegible]ally open.

From this experiment we learned the following:

1. Single grains of .023 web propellant will conduct current.
2. Current is sustained to power and energy levels that cause arcing without the grain being initiated.
3. After arcing for a few seconds, the grain acts as a switch, turning off the current.

2.2 FORMAL EXPERIMENTS

2.2.1 Fixture

The electrical properties of M-9 propellant were to be determined as outlined in the plan of research. First consideration was given to a fixture which would hold the propellant sample and perturbate the experiments as little as practicable. The fixture of Figure 2-1 was designed for this purpose.

Features of the fixture are illustrated in the figure. The main interest was to have the walls and holder electrically and chemically inert. Teflon was chosen as the main construction material. Sample thickness could readily be determined using a micrometer to measure the distance between the C-clamp faces with and without the sample present. Condensed moisture effects would be minimized using Teflon. The walls of the Teflon cylinder were pierced with very small holes to allow "breathing" in the sample space and thereby quick acclimation of the propellant sample to the environment.

2.2.2 Procedure for Loading Samples

The sample holders were prepared for environmental testing by mounting them close to the connector panel inside a Murphy and Miller environmental chamber.

Seven sample holders were used. Four were loaded with .006 web propellant, two with .023 web and two control holders employed in air dielectric.

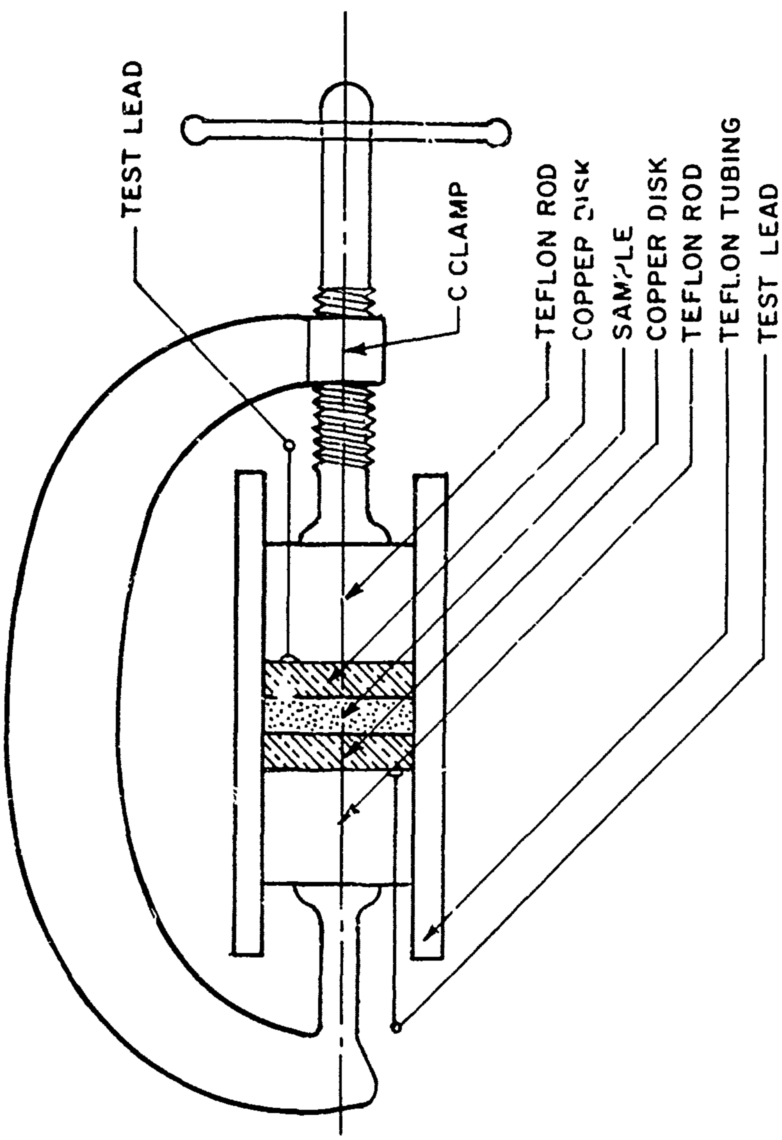


Figure 2-1. Fixture for Propellant Evaluation

Holders were filled with preweighed samples of propellant chosen to give reasonable electrode spacing. Dimensions of the gap were adjusted to give an initial resistance of 20 kohms for the .006 web propellant and of 500 ohms for the .023-web propellant prior to gap measurement. The electrodes were then clamped in place and allowed to remain in the clamped position throughout the environmental testing. Gap sizes are listed in Section 2.3.3.

2.2.3 Measurements of Capacitance

Measurements were first made using a General Radio GR1650 bridge with a General Radio GR1232A null detector to indicate bridge balance. The bridge was excited with a Hewlett Packard 200AB audio generator at frequencies from 1KHz to 20 kHz. After reading the capacitance, which required much adjustment due to a broad null, the results of these measurements yielded values of capacitance that were unreasonably high for the element dimensions. A check of the system was made using a 5 picofarad capacitor shunted by a 20,000 ohm resistor. The 1615A bridge gave a reading of 150 picofarads with a D greater than 50 for frequencies from 1 kHz through 20 kHz. With this checking procedure, we presumed that readings on explosive samples were also in error. To make the capacitive reactance more equal to the shunt resistance, the measuring frequency was increased to 10 MHz; and to compensate for the increased frequency, a GR 821A bridge was used. This procedure gave a reading of 2 picofarads for the sample holder which was consistent with electrode dimensions and spacing.

Further measurements of capacitance were made using the 10 MHz system.

2.2.4 Resistance Measurements

Resistance measurements were made using a Keithley milliohmmeter, Model 503.

2.2.5 Breakdown Strength

Breakdown strength is normally considered to be a property of insulators. Graphited propellant such as the M-9 is more accurately described as a semiconductor. For this reason voltage breakdown per se, does not exist. Conduction begins immediately when voltage of very low level is applied to propellant samples. Breakdown may be viewed in a number of ways, one of which is radical departure from previous behavior.

For these reasons, it was decided to apply increasing voltage in increments until some departure from normal occurred or until some notable event occurred. Sample holders described earlier were to be used for these studies.

2.3 RESULTS OF EXPERIMENTS

2.3.1 Capacitance

Measurements were made under controlled conditions of temperature and humidity indicated in Table 2-1. Capacitance due to the sample propellant was determined by subtracting the average capacitance measured in the two air-dielectric sample holders from the capacitance of the sample holders containing propellant. These measurements were made at 10 MHz as explained earlier.

It was not possible to obtain a null on the .023-web propellant. The most probable reason for this is the much lower resistance of this larger grain propellant.

A ten day period was allowed to ascertain effects of aging on measurements. During this time span the propellant materials were allowed to remain in the sample holders with the electrodes locked in position. For comparison purposes, two runs were made at conditions close to those used previously, -20°F and 76°F @ 65% RH. In addition, one set of measurements was made at -65°F. These results are also shown in Table 2-1.

Table 2-1. Capacitance* (picofarads)

Temp.	Sample Humidity	Data Summary 1 (.006 web)	2 (.006 web)	3 (.006 web)	4 (.006 web)	5 / 6 (.023 / web)	7 Air Control Mean	7 Air Control σ
-20**	Low	1.0	4.0	1.7	4.5	Could not read capacitance on .023 webb	2.8	1.7
74°	61% RH	2.52	0.9	0.94	4.6		2.23	1.74
75°	40% RH	3.6	2.0	2.4	8.0		4.0	2.75
160°	30% RH	3.8	1.8	2.2	7.8		3.9	2.73
160°	98% RH	-2.0	5.4	7.0	6.0		5.10	2.16

* Cap is that value found by subtracting air control form M-9-filled sample holder.
** -60 desirable. Could only achieve -20°F.

After 10-Day Delay

-20	low	9	.6	1	4.4
76	65	2.8	1.8	2.1	5.4
-65	low	3.1	2.2	1.7	6.1

2.3.2 Resistance

a. *Temperature - Humidity*

Resistance Measurements were made immediately after capacitance measurements. Conditions may be considered the same as those for the capacitance measurements.

Results of resistance measurements are shown in Table 2-2 where temperature and humidity are the variables.

b. *Mechanical Loading*

Loading of the propellant by either its own weight or by an externally applied weight could be of considerable importance in practice. Loading plants transport, convey, store and package propellants in a number of ways. Loading was accomplished by application of weight to a platform that exerted force on the top of the sample holder described earlier. Initial length was measured, then deflection was measured after application of weight. Results are given in Table 2-3.

c. *Temperature*

Temperature effects on resistance were monitored for short term temperature cycles using four sample holders. Table 2-4 shows the results of these tests. Holders 2, 3 and 4 contained .006 web propellant and holder 5 contained .023 web propellant. Holders were unchanged in position from earlier experiments.

2.3.3 Resistivity

Resistivity was computed from the resistance data reported in Table 2-2 by the following equation:

$$e = \frac{R\pi d^2}{4t}$$

where e = resistivity - ohm cm
R = resistance - ohms
d = diameter of fixture - cm
t = sample thickness - cm

Sample thickness was measured for each of the sample holders used in these experiments. The thickness is listed as sample holder Number

Table 2-2. Resistance Data (K ohms)

Temp.	Humidity	1	2	3	4	5	6	7	8	1, 2, 3, 4		5 - 6	
		.006				.023		Air Control		M	σ	M	σ
-20°	Low	130	250	800	300	19	19	---	---	370	295	19	0
74°	61%	43	250	47	40	0.7	1.0	---	---	95	103	0.85	0.2
75°	40%	43	500	380	65	1.7	3.4	---	---	247	228	2.55	
160°	30%	450	240	170	170	1.1	1.4	---	---	257	133	1.25	
160°	98%	75	70	70	65	5.4	5.8	---	---	70	4.08	5.6	
					After 10-Day Delay								
-20	Low	250	800	1700	650	45	60						
76	65	670	2800	2200	500	47	50						
-65	Low	400	300	620	190	2.8	5						

Table 2-3. Effects of Dead-Weight Loading on M-9 Propellant

Applied Weight (lbs)	Deflection (mils)	Resistance (k ohms)
	0.23 web	
0	0	25
1	3	5.5
2	12	2.5
4	31	1.3
6	35	1
9	36	.56
17.5	59	.26
	.006 web	
0	0	200
1	5	100
2	11	50
4	16	35
6	20	27
9	25	21
17.5	28	15

Table 2-4. Effects of Temperature on Resistance

Sample Number / Temp (Humidity)/Time	Resistance (k ohms)			
	2	3	4	5
°F (%)/min				
77 (70)/0	3600	580	400	30
50 (50)/30	2400	600	400	20
-20 (Low)/40	2000	1300	400	22
-65 (Low)/60	400	650	700	25
-65 (Low)/90	480	680	800	4
-65 (Low)/120	500	620	450	3.7
-65 (Low)/150	540	580	450	3.7
-65 (Low)/180	440	600	500	3.7
-65 (Low)/210	440	600	640	4.1
+80 /240	2500	2300	2000	50 to 100
+140 (31)/255	5000	2200	4500	3000
+150 (82)/270	400 to 500	850	800	90
+160 (98)/300	300	340	240	5 to 8
+160 (98)/330	270	280	80	6
+160 (98)/360	280	270	80	7

(thickness in cm): 1(.560), 2(.546), 3(.500), 4(.584), 5(1.14), 6(1.07). Sample holder diameter was .75 inches (1.905 cm). Resistivity reported in Table 2-5 was computed by the equation above.

2.3.4 Conductivity and Conductance

Conductivity is the reciprocal of resistivity. Table 2-6 was computed by taking the reciprocal of the values in Table 2-5.

Conductance was measured at 10 MHz along with capacitance. These values are given in Table 2-7.

Initial measurements were made of propellant weight, 1.0264 grams; volume, 1.2077 cc and density, .8498. Increased density was achieved by continued compression of the sample.

2.3.5 Breakdown Strength

Breakdown strength or dielectric breakdown is a property generally attributed to dielectrics. Since M-9 propellants of the type considered in the study are semiconductors, a normal dielectric breakdown test is inappropriate. Samples were tested in the holders used for other testing on this project with the results indicated in Table 2-8.

Initial measurements were made of propellant weight, 1.0264 grams; volume, 1.2077 cc and density, .8498. Increased density was achieved by continued compression of the sample.

Table 2-5. Resistivity of M9 Propellants
(K ohm cm)

		1	2	3	4	5	6		1, 2, 3, 4		5, 6	
Temp	Humidity	.006 web				.023 web			mean	std dev	mean	std dev
-20	low	661	1304	4560	1464	47.5	50.6		1997	1743	49	2.19
74	61	219	1304	228	195	1.75	2.66		486.5	545	2.2	.64
75	40	219	2609	2166	317	4.25	9.05		1328	1238	6.65	3.39
160	30	2290	1252	969	829	2.7'	3.72		1335	661	3.23	.67
160	98	381	365	399	317	13.5	15.5		336	35	14.5	1.41

Table 2-6. Conductivity (u mho/cm)

		1	2	3	4	5	6		1, 2, 3, 4		5, 6	
Temp	Humidity	.006 web				.023 web			mean	std dev	mean	std dev
-20	low	1.51	.766			21	19.8		.79	.52	20.4	.84
74	61	4.57	.766			571	375		3.71	1.98	473	139
75	40	4.57	.383			235	110		2.14	2.06	173	88
160	30	.430	.798			364	268		.86	.33	316	68
160	98	2.62	2.73			74	64.7		2.75	.26	69.4	6.6

Table 2-7. Conductance Data - 10 MHZ (μ mhos)

Temp.	Humidity	M	σ	1	2	3	4	5	6	7	8	M
					(.006 web)			(.023 web)				
-20°F		384	18	360	400	380	395	--	--	260	350	305
74°	61%	595	39	610	550	580	640	--	--	350	350	
75°	40%	613	98	560	560	570	760			315	--	
160°	30%	990	20	1000	1000	960	1000			1000	1000	
160°	98%	35 over 1000										

Conductivity could not be read on .023 web samples.

After 10-Day Delay

-20	Low	1000	1000	1000	1000
76	65	560	540	570	590
-65	Low	1000	1000	1000	1000

Table 2-8. Breakdown Strength - Conductivity Measurements (.006 web Propellant)

Density	0.85			Density -- 1.18			Density 1.29		
E (volts)	I (ma)	R (k ohms)	P (MW)	I	R	P	I	R	P
5	0.265	18.86	1.32	1.5	3.33	7.5	1.65	3.03	8.25
10	0.550	18.18	5.5	3.4	2.94	34.0	3.45	2.90	34.5
15	0.862	17.4	12.9	5.0	3.0	75.0	5.45	2.75	81.8
20	1.42	14.1	28.4	6.8	2.94	136.0	7.0	2.86	140.0
25	1.82	13.74	45.4	---	----	-----	---	----	-----
30	2.22	13.51	66.6	---	----	-----	---	----	-----
35	2.62	13.36	91.7	---	----	-----	---	----	-----
40	3.08	13.0	123.0	---	----	-----	---	----	-----
50	3.72	13.4	186.0	18.0	2.78	900.0	20.0	2.5	1000.0
100	8.30	12.04	830.0	---	----	-----	---	----	-----

3. ELECTRICAL EXCITATION OF PROPELLANTS

3.1 INITIAL EXCITATION OF PROPELLANTS

3.1.1 Equipment

a. *Pulse Generator*

The equipment for supplying electrical energy consists of a coaxial transmission line over 500 ft. long. The line has a characteristic impedance of 50 ohms and is charged from a power supply 0-100,000 volts. For our experiments the limiting voltage was about 35,000 volts. A simplified diagram of this equipment is shown in Figure 3-1(a).

The charged line is switched into a terminating resistor of the same resistance as the characteristic impedance of the line, producing what is essentially a rectangular pulse. Current calibration is carried out using the rectangular pulse. A current probe is located in series with the 50-ohm termination and a voltage probe is placed across the termination. A voltage measurement across the termination allows the current to be determined (measured voltage divided by 50 ohms). This procedure permits the current sensitivity of the probe to be expressed.

During firing attempts, the 50-ohm termination is allowed to remain on the line as shown in Figure 3-1(b). The current probe is inserted in series with the load under test. Both the load under test and the probe (in series) are shunted across the 50-ohm termination. This method of pulse excitation was used throughout the electrical excitation tests.

b. *Photography*

Early tests were made with no photography and at times without photographing oscilloscope traces. This procedure was changed after a short time of experimentation when few samples fired; and when, in fact, the definition of firing became difficult.

At first open shutter photographs were made which gave a complete light history of the events. This was done with a Polaroid camera and close-up lenses. Later, an Abtronics Model 2

F-C3854

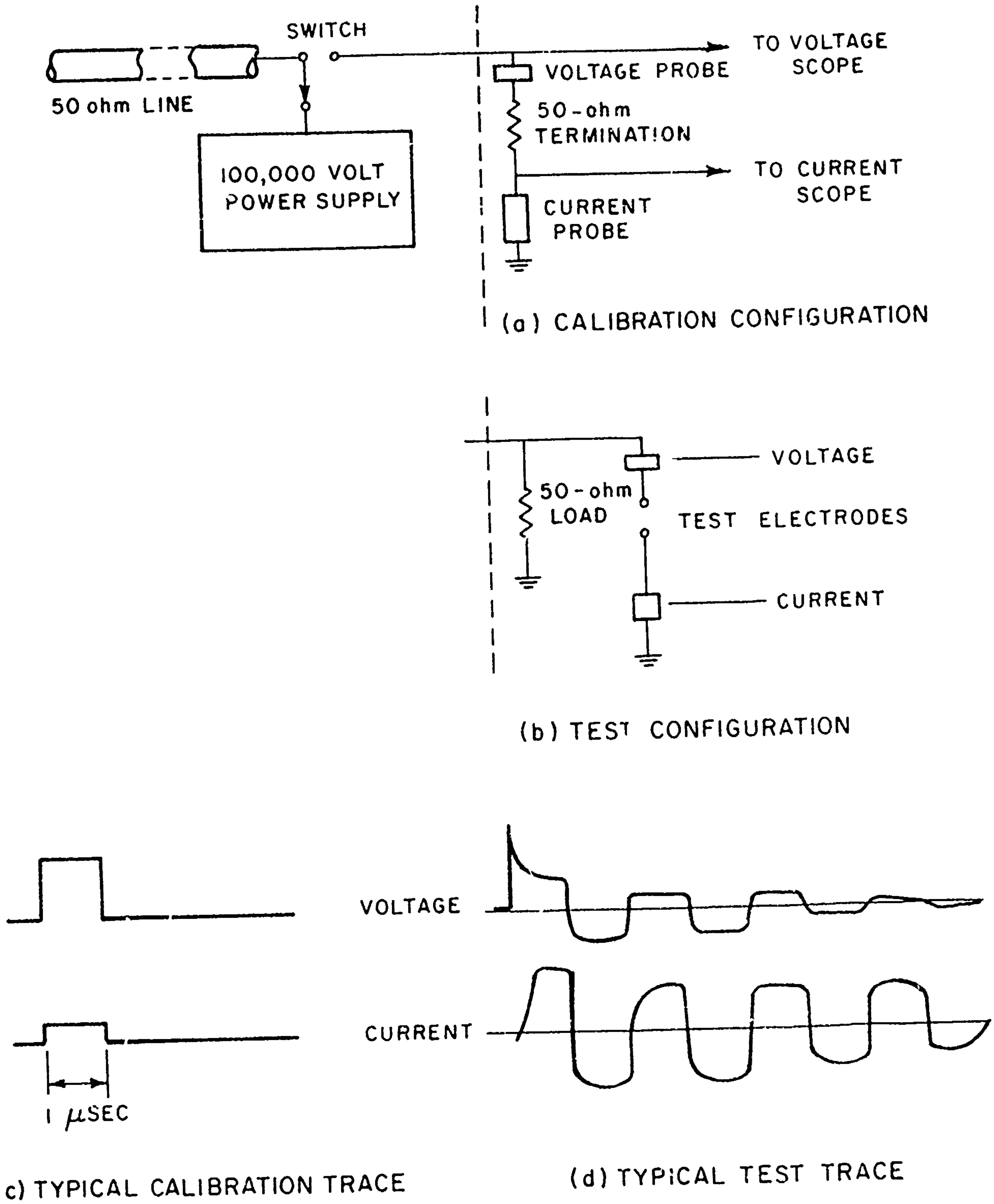


Figure 3-1. Instrumentation for Pulse Application

electronic camera was used. The advantage of the Abtronics camera rests in very short exposure times, one microsecond or less, and in the ability to set the time at which exposure occurs from a given synchronization pulse. The delay time is adjustable from 0.5 to 100 microseconds. The unit used had two cameras so that two photographs could be taken. One of the two cameras produced a picture of poor quality, the cause of which was traced to a bad biplaner image converter tube that could not be replaced readily.

c. *Waveforms and Energy Analysis*

Typical traces from the oscilloscopes for current and voltage are illustrated in Figure 3-1. Under calibration conditions, the current and voltage pulses are rectangular (c). When breakdown or sparking and aging occur, the line "sees" something other than its characteristic impedance and reflects an open circuit to the source. Reflections continue on the line until the energy is dissipated (d).

Energy is determined by manual integration of the instantaneous product of current and voltage over the length of the waveform. This way of determining the energy gives a measure of the energy actually deposited in the load. The calculation process eliminates the use of initial stored energy as a lasting criteria. The process of calculating energy is illustrated in Figure 3-2.

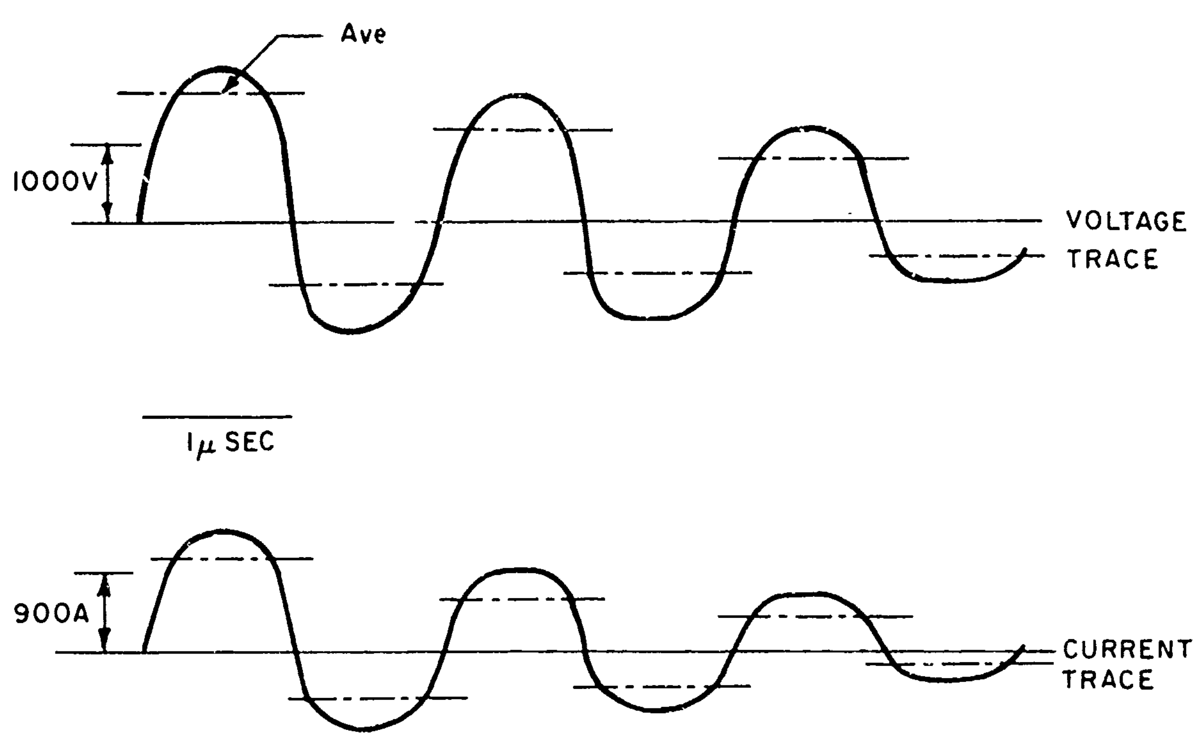
3.2 DISCHARGE TESTS

3.2.1 Early Tests

Early tests were made with electrodes as shown in Figure 3-3. A few tests with these fixtures showed some evidence of propellant burning. The washer closing the fixture of Fig. 3-3(a) was moved from its initial position and left suspended by a single soldered wire used to hold the washer in place. Sniffing the air gave the odor characteristic of burning propellant immediately after exposure of propellant to discharges in the range from 10 kV to 35 kV.

These evidences of burning were of interest, but we desired a more pronounced indication of firing. To concentrate the plasma from the discharge, the fixture of Figure 3-3(b) was constructed. The first experiment with this fixture resulted in what we determined to be a

F-C3854



ENERGY - DEFINITION

$$W = \int_{o}^{t} E(t)\ I(t)\ dt$$

W - Energy (Joules)

E - Voltage (Volts)

I - Current (Amps)

t - Time (Sec)

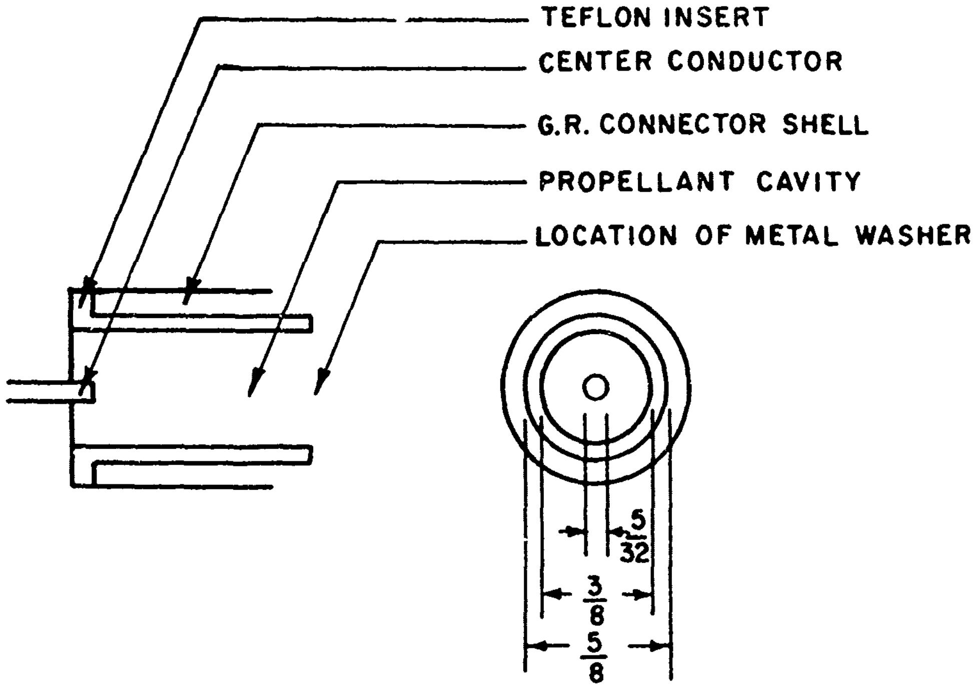
Energy - Cycles

$W + \bar{E}\bar{I}\Delta t$

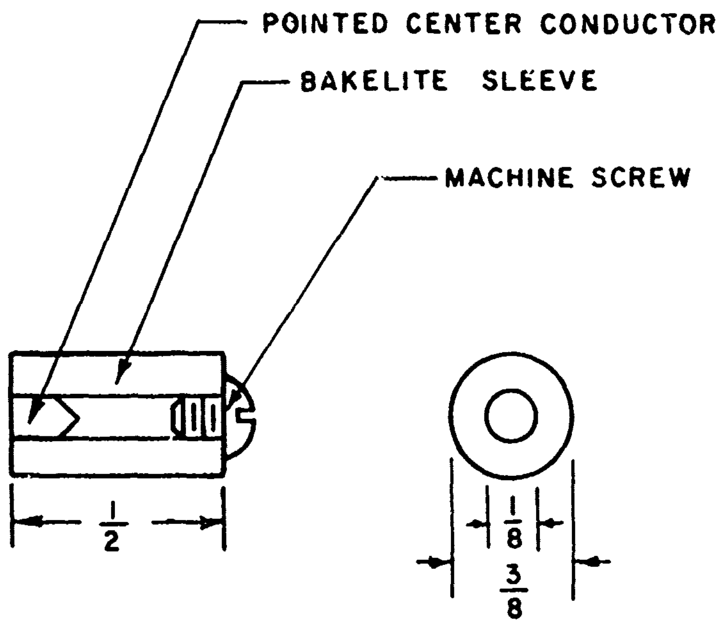
	$\bar{E}$		$\bar{I}$		Δt	W
	Div	Cal	Div	Cal		
1st Cycle	1.8	1000	1.2	900	10^{-6}	1.944
2nd Cycle	.8		.7			.504
3rd Cycle	1.2		.6			.648
4th Cycle	.7		.5			.315
5th Cycle	.8		.4			
6th Cycle	.4		.2			.072

W = 3.77 Joules

Figure 3-2. Method of Computing Energy Content of Exposure



(a) Propellant Testing Insert for General Radio Connector



(b) Insert for Propellant Test Fixture

Figure 3-3. Fixtures for Application of Electrical Pulses to Propellant Samples

"fire". Excitation was at 30 kV on the coaxial line. Voltage and current traces were taken and observed to be of the general type sketched previously in Figure 3-2. Peak currents were on the order of 400 amperes at voltages around 600 volts.

Success on this first experiment encouraged more tests to be run. Those for which analysis was carried out are summarized in Table 3-1.

Table 3-1. Exposures for Which Energy was Computed

Shot No.	Line Charge (k Volts)	Measured Energy (Joules)	Web	Result
31-1	35	3.82	.006	Gas Produced
34-2	30	2.23	.006	Fired
34-3	20	1.95	.006	No Fire
35-1	25	2.55	.066	Fire
35-2	22.5	1.75	.006	Gas Produced
35-3	25	2.19	.006	Repeat of 35-2 (Same Propellant)
36-3	20	1.86	.006	Fire

Firing energies were computed for each of the shots listed in this table. Minimum firing energy was 1.86 joules. All propellant samples were of the .006-web size.

3.2.2 Firing Attempts with Concurrent Photography

a. *Open-Shutter Photography*

The next step in examination of propellant sensitivity was to place a transparent cylinder around the propellant sample to observe reactions. Visual observations were attempted first. While flashes could be observed, the human eye integrated results without much recollection of events or conditions.

A single-frame camera was brought into use at this time. Samples were fired with the room darkened while an open-shutter, close-up camera was focused on the sample holder.

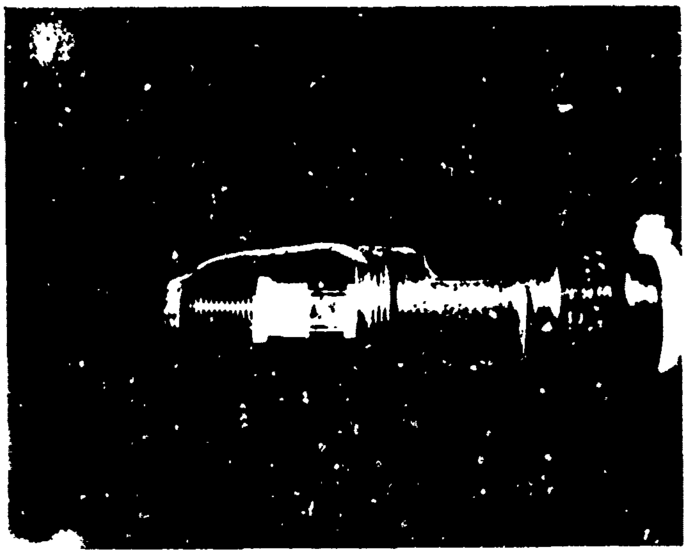
Results of these tests are shown in Table 3-2 below.

Table 3-2. Results of Firing Tests

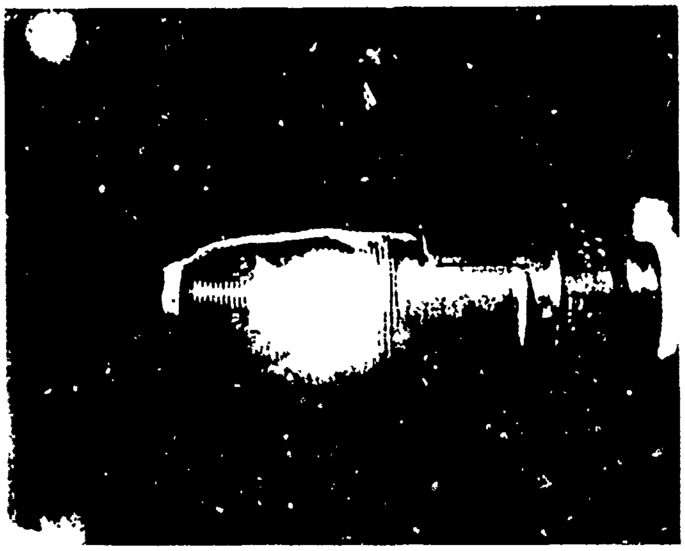
No.	Initial Voltage	M-9 Web	W(Joules)	Notes on Photo
59-2	15 KV	.006 (New)	.607	D,G Self illumination
60A-1	20 KV	.006 (Repeat)	1.20	B,D Very bright
61	20 KV	.006 (New)	1.40	D " "
62	20 KV	.006 (New)	1.61	F " " Arc (Color)
63	20 KV	.006 (New)	1.32	F,D,B Med. bright (Color)
64	20 KV	.006 (New)	1.60	F,D Low " (Color) Grain Visible
65	20 KV	.023 (New)	1.54	F,D
66-2	27 KV	.006 (Ground)	.862	F
67	20 KV	.006	1.19	D Microscope camera
68	20	.006	1.34	D
69	20	.023	1.35	F
70	27	.023	1.91	F Web clear Burn marks on glass All powder consumed
71	31	.023 (Powder)	4.21	F,G All powder burned Glass case disintegrated
72	30 No fire	.006 (Powder)		
	35 Fire		3.05	F,G Glass disintegrated
73	12 Fire	.006	.385	F,D 1/16th gap, .023 web
74-B	12 Fire	.023	.354	F,D 7/32th gap

NOTES: B - Burned; G - Glass Tubing Broken; D - Discoloration of Propellant Grain; F - Fired

Figure 3-3 is a photograph of .006-web propellant being excited (Shot 59-2, Table 3-2, and Fig 3-4) is a similar exposure at a higher voltage. In each of the two shots illustrated, the propellant was discolored and the glass tubing was cracked.



(a) Propellant Being Excited at 15kV
(Shot 59-2)



(b) Propellant Being Excited at 20 kV
(Shot 60A-1)

Figure 3-4. Open-Shutter Photography of Excited Propellant

b. *Electronic Camera Photography*

Results of open-shutter photography and observations while using the recording method left questions concerning what was actually happening to the propellant grains.

The physical condition of propellants after exposure to discharges indicated that the graphite coating was being eroded with each exposure. Figure 3-5 demonstrates this for a number of initial voltages and for numbers of exposures at different voltages. In each experiment, a recovered grain of propellant is compared with a previously unexposed grain. The exposed grains, on the left, show a change from opacity (just like the unexposed grains) with low-voltage, single exposures or single high-voltage exposures.

Nos. 4 and 6 are typical results for single exposures to 10 kV for both web sizes used in these experiments; practically unaffected. These results may be compared with Nos. 13 and 11 which were excited at 30 kV, No. 13 with one exposure and No. 11 with six exposures. Both of these heavily-exposed grains are translucent. What happened to the propellant during and shortly after exposure were questions that could be best answered by short-exposure photography during this relatively short time interval.

The Abtronics camera described earlier was brought into play at this time. To use this camera effectively it was necessary to repeat firings, increasing the time interval from the start of the pulse to the time at which a one-microsecond exposure was taken. In this manner, assuming some uniformity in performance from sample to sample, a time history of light output from the propellant could be obtained. A typical exposure series is depicted in Figure 3-6.

Three such series of photographs are summarized in Table 3-3. All tests depicted in this table were made with .006-web propellant. The first series, 64R through 66, were excited at 15 kV. Energy was being applied for the first 10 microseconds of this series. For 15 microseconds following removal of electrical energy, the propellant continued to issue light in ever decreasing amounts. Either the reaction was started or particulates remained at a very high temperature during the time that electrical energy was no longer supplied.

The next series, Record 67 thorugh 73L, was run at 20 kV initial charge. Light output was greatest in the first 5 microseconds of energy application. At 20 microseconds there was no longer any electrical input to the sample, but light output continued through 20 μseconds to 40 μseconds (25 microseconds after termination of electrical input).

Sample No.	Exposure Voltage	Times Exposed	Exposed Sample	Unexposed Sample
1	15	1		
2	15	1		
3	12.5	1		
4	10	1		
5	20,25	2		
6	10	1		
7	15	1		
8	20,25,30	3		
9	30	1		
10	30	6		
11	30	6		
12	25	2		
13	30	1		
14	15	4		
15	15	2		
16	15	10		

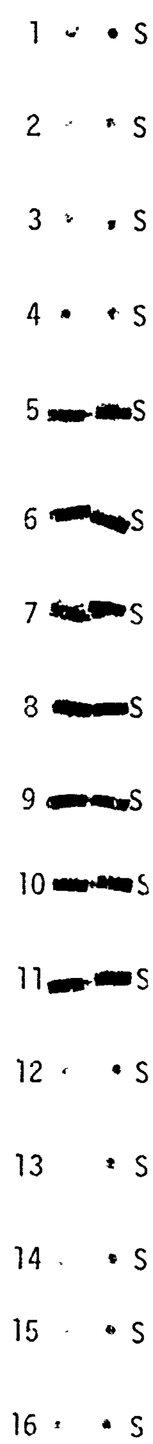
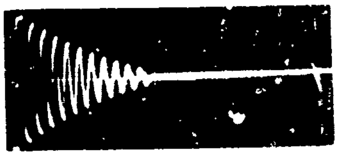
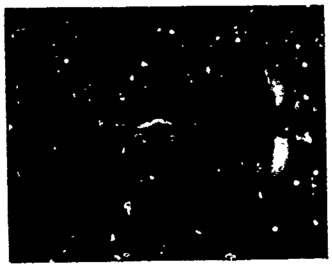


Figure 3-5. Results of Propellant Erosion from Electrical Exposure



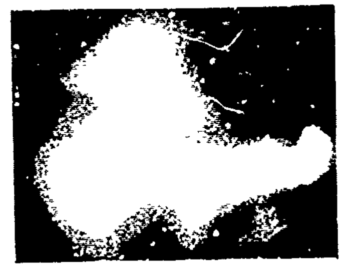
Current Trace
196 Amp/Div   10 μ sec/Div

Voltage Trace
2780 Volts/Div   5 μ sec/Div



5 μ sec

22 μ sec



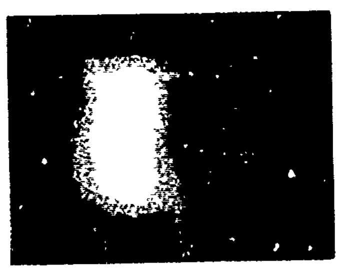
27 μ sec

38 μ sec

43 μ sec

47 μ sec

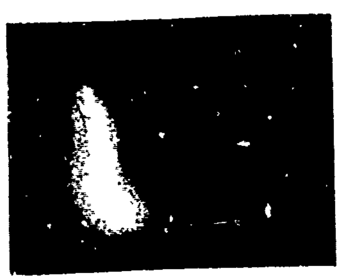
50 μ sec



57 μ sec

60 μ sec

66 μ sec



72 μ sec

83 μ sec

Figure 3-6. Timed Photography of Electrically Excited Propellant

Table 3-3. Results of Applied Voltage-Time Experiments with M-9 Propellant

Record No.	Initial Voltage (kV)	Energy (Joules)	Photo at time (micro sec)	Notes
64R	15	.348	5	med. bright
64L	15	.330	10	brighter than 63R
65R	15	.272	15 (NEI)	less than 64L
65L	15	.342	20 (NEI)	less than 65R
66	15	.164	25 (NEI)	just discerned
67	20	.535	5	very bright
68	20	.533	10	less than 67
69	20	.463	15	less than 68
70	20	.511	20 (NEI)	less than 69
71	20	.462	25 (NEI)	less than 70
72	20	.545	30 (NEI)	less than 71
73R	20	.387	35 (NEI)	less than 72
73L	20	.419	40 (NEI)	dim spot
74L	20	0.0524	5 (NEI)	dim light
75R	20	0.0721	10 (NEI)	very dim
75-1R	20	1.09	15 (NEI)	burning
75-1L	20	.530	20 (NEI)	burning

NEI - No electrical input at this time
Prior to 74L 0.5 grains of propellant used
For 74L and thereafter, 1 grain used.

One-half gram of propellant was used for the first two series of tests. For the third st series (74L through 75L) the explosive sample weight was doubled to 1 gram.

It will be noted that the last test series had significantly lower energy associated with the first two exposures. Also note that at the 5- and 10-microsecond exposures there was no electrical input to the sample, the light was much less than for other exposures. For the next two shots (751R and 75IL) energy input was more consistent with other exposures. There were signs of burning at 15 and 20 microseconds delay.

3.3 DISCUSSION OF RESULTS OF PULSE EXCITATION

3.3.1 Instrumentation

The pulsed instrumentation provides pulses for which the actual energy delivered to the sample under test is determined. This accomplishment allows evaluation in terms of a more realistic heat-producing perimeter than was allowed previously. Similar exp -s in terms of initial voltage result in widely different energy delivery.

Direct photography of the results of e -riment gives an indication of what is occurring within the propellant while multaneous current and voltage traces are being recorded.

3.3.2 Particle Size

Most experiments were made using the .006 web propellant; however experiments were also made with propellant that had been shaved in a pepper mill and with .023 propellant. The only propellant which exploded to the extent of fragmentation of the case with high velocity particles was the pepper-mill shaved material. Energy input to the system was around 3 to 4 joules. Initial voltages were set for 30 to 35 kV for exploding the shaved propellant.

3.3.3 Gap Size

Gap size and shape may be of some importance and several tests were made in an effort to discover how gap size affected firing. A 1/8-inch gap at 12 kV initial voltage gave no breakdown in .006-web propellant.

Reducing the gap to 1/16-inch resulted in a breakdown and in a normal fire as evidenced by sound light output and discoloration of the grain. Energy computations on these shots showed that 0.380 joules was delivered to the samples. The energy level was considerably lower than results reported elsewhere, however the other results were reported in terms of the energy stored in a capacitor and not the energy delivered to the propellant.(4) Furthermore, the propellant was not as confined as the samples run in the tests reported here.

3.3.4 Post-Exposure Condition of Grain

In several exposure tests, the graphite coating was found to be removed from the propellant grains. This process seemed to begin at initial voltages between 10 and 15 kV. No change was evident at 10 kV. There is a slight erosion of graphite at 12.5 kV. Repeated exposures at 15 kV continued to erode the graphite.

3.3.5 Photographs of Reactions

Examination of photographs after termination of electrical pulses up to 70 microseconds after the beginning of a pulse, approximately 45 microseconds after energy input ceased, showed plasma still issuing from the propellant grains. The light output diminished with time and finally ceased At times there was a build up of light during electrical energy application.

From the evidence at hand, a surface reaction appears to form in which the graphite coating is heated from the electrical energy. The propellant surface begins to burn, but the burning volume is so slight that insufficient energy is present to continue the process. Propellant recovered after exposure indicates loss of graphite. Graphite deposits were found on the housings along with "imprints" of the propellant grains.

4. DISCUSSION OF PROGRAM RESULTS

4.1 CONDUCTIVITY, RESISTANCE AND CONDUCTANCE

M-9 propellant is not a highly conductive material; neither is it a dielectric. The conductance arises from the graphite coating which has been calculated to be about 4.5×10^{-7} cm thick on the .023-web grain (see Appendix B).

Bulk resistivity of the propellant at 75°F, 40% relative humidity is 1.328 megohm-cm, which is in the semi-conductor range.

Resistance as a function of temperature is summarized in Figure 4-1. The trend is downward, as would be expected for graphite. Some humidity effects may be present here. It is not practical to measure relative humidity at -20°F.

Conductance at 10 MHz shows a definite rise with increasing temperature as is indicated in Figure 4-2.

Humidity has a pronounced effect on resistance at both 75°F and 160°F as can be observed in Figure 4-3. Greater downward slope is noted at 75°F.

Conductance at 10 MHz (Fig. 4-4) seems less affected by humidity than does resistance. At 160°F humidity seems to increase conductance, as would be expected. At 70°F however the conductance decreases with increasing humidity.

4.2 DIELECTRIC CONSTANT

Dielectric constant is directly related to geometry and capacitance. Capacitance data for the .006-web propellant was averaged for each condition under which tests were made. These average values of capacitance (plotted as a function of temperature in Fig. 4-5 and as a function of humidity in Fig 4-6) were divided by the air reference.

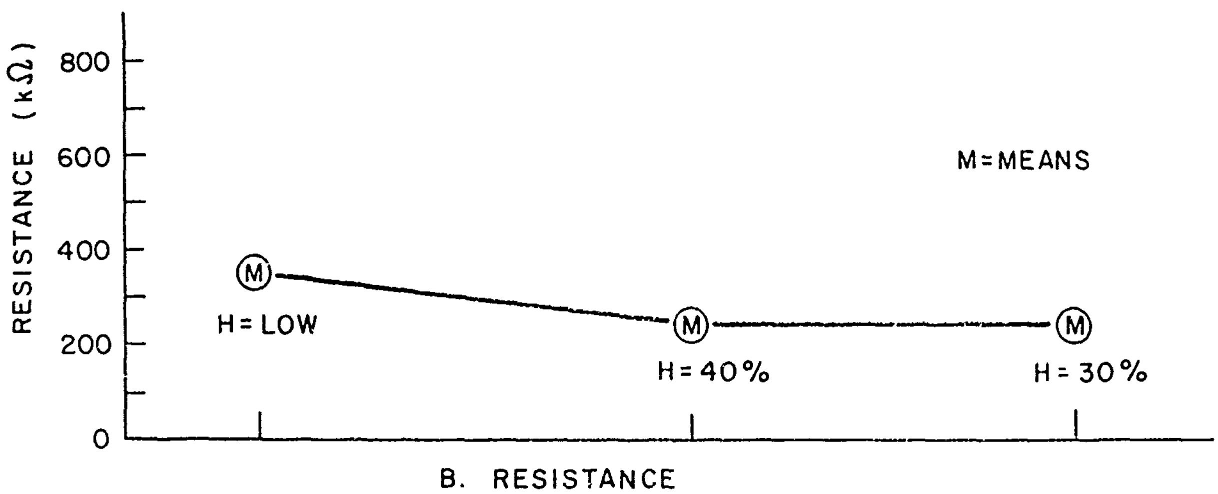


Figure 4-1. Temperature Effects on Resistance

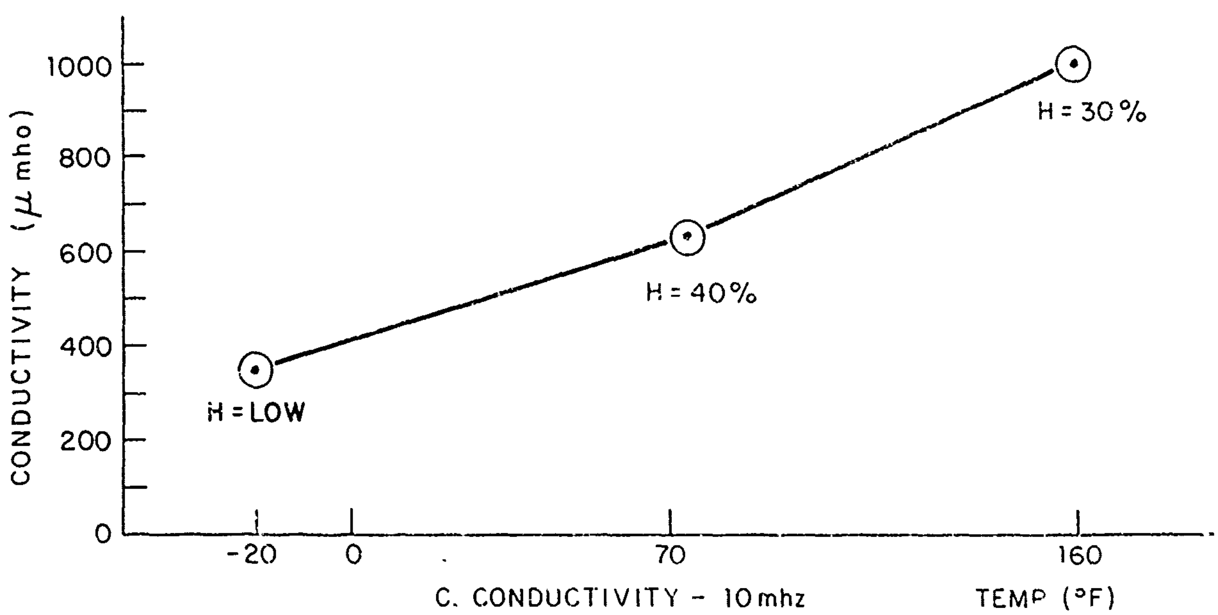
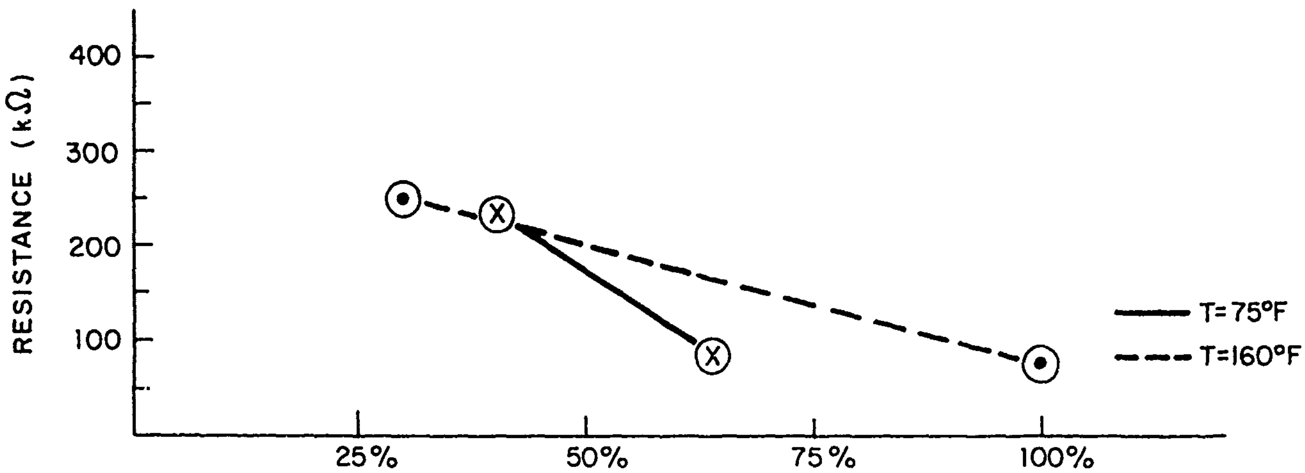
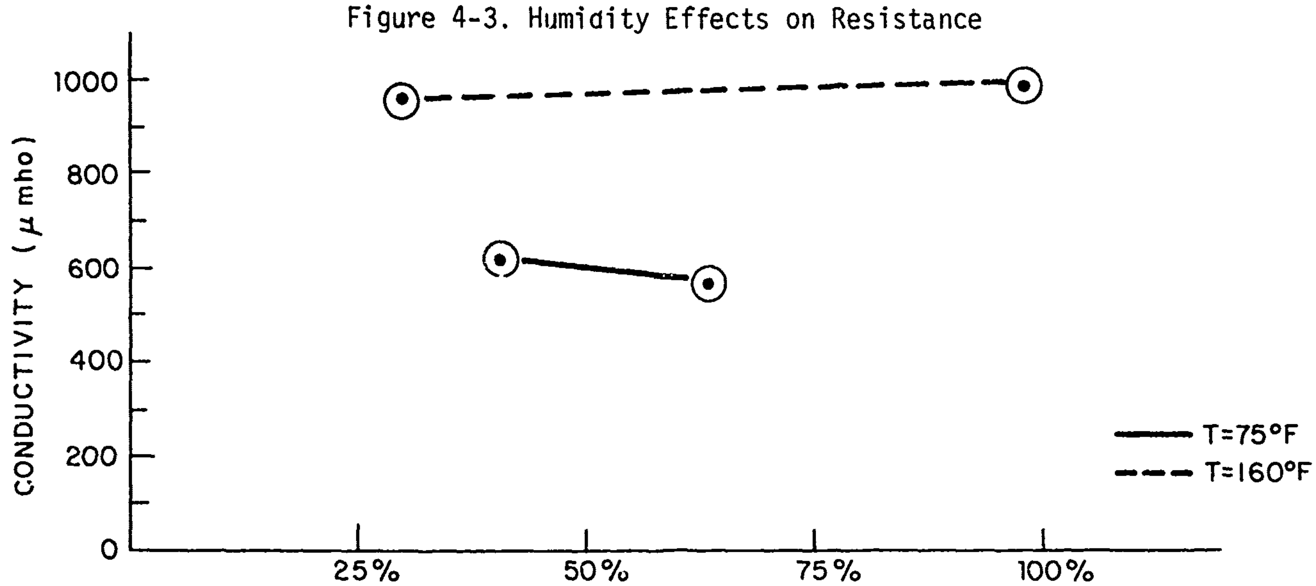


Figure 4-2. Temperature Effects on Conductance



B. RESISTANCE EFFECTS

Figure 4-3. Humidity Effects on Resistance



C. CONDUCTIVITY - 10 mhz

Figure 4-4. Humidity Effects on Conductance - 10 MHz

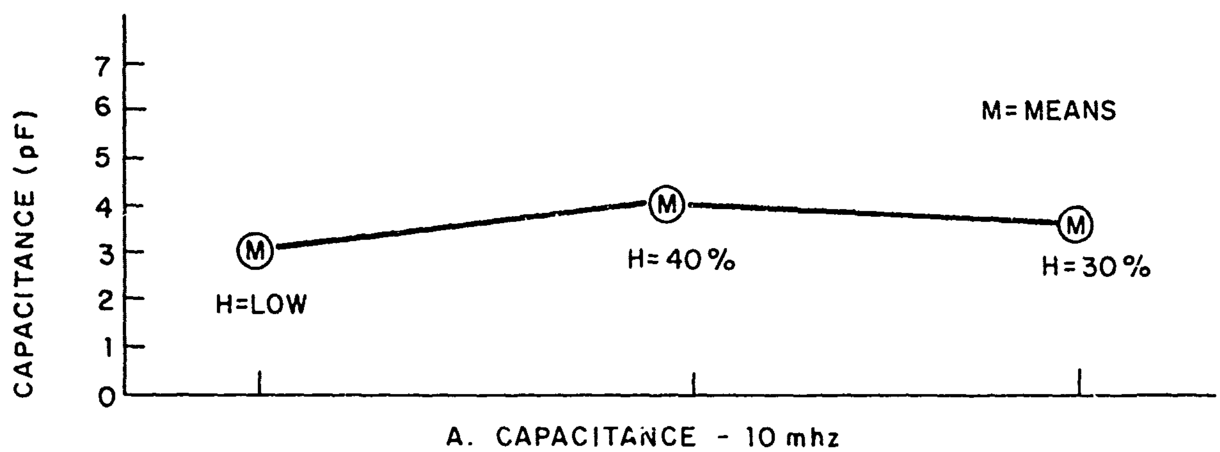


Figure 4-5. Temperature Effects on Capacitance - 10 MHz

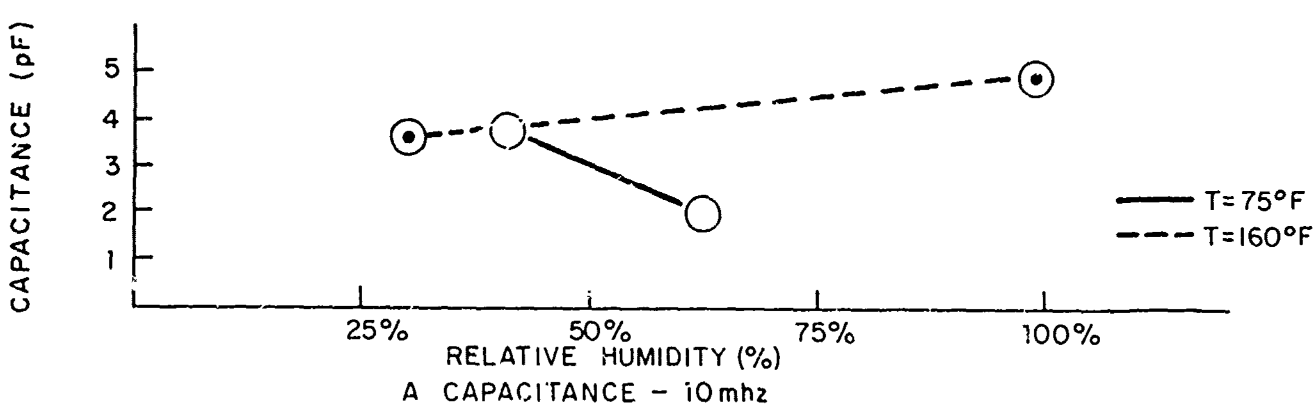


Figure 4-6. Humidity Effects on Capacitance - 10 MHz

Results are given in Table 4-1 below. Dielectric constant is close to unity for all of the measurements that were made. Temperature and humidity appear to have small effects on dielectric constant, if any.

Table 4-1. Dielectric Constant of M-9 Propellant
(.006 Web)

Temp	Humidity	Capacitance (pF) 1	2	3	4	Capacitance (pF) Mean	STD Dev.	Relative Dielectric Con.
-20	low	26	29	26.7	29.5	27.8	25	1.11
74	61	36	34.3	34.4	38	35.68	33.4	1.07
75	40	28.6	27	27.4	33	29	25	1.16
160	30	38	36	36.4	42	38.1	34.2	1.11
160	98	30	37.4	39	38	36.1	32	1.13

4.3 HYSTERESIS

Hysteresis effects are present mainly in a resistance sense. Excessive currents, voltage and their integrated effects in the form of energy and power do cause irreversible changes in the material as will be noted later.

Pure capacitance exhibits no hysteresis. When the dielectric possesses some loss which appears as a resistance, hysteresis is present. Electrical hysteresis is present in M-9 propellant from a rather large shunting resistance. The capacitive reactance was about the same as the resistance at 10 MHz. The relatively low value of resistance due to the graphite masked other properties of the propellant. It must be remembered however that graphite is an integral part of the propellant.

Some hysteresis is present with simply age of the sample. These samples allowed to stand for 10 days (Table 2-1 and 2-2) showed marked changes in capacitance and resistance. Capacitance shifted both ways.

In one case a 9-fold increase was noted (Sample 1, Table 2-1). Samples 2, 3 and 4 all showed decreases in capacitance. Factors brought about by the 10-day delay caused resistance to increase about two-fold in all samples.

4.4 BREAKDOWN STRENGTH

Breakdown strength is normally considered a dielectric property. Potential is applied to a given thickness of the material until a pronounced upturn in current is noted (breakdown). The voltage is divided by the sample thickness to give breakdown strength in volts/mil. Conductance in M-9 propellant begins when voltage is applied and continues as long as potential is applied or until a limit is reached in the dissapted properties of the graphite coating. Figure 4-7 shows the results of potential application to samples of three different densities (all are .006-web). Resistance decreases as power is increased. Greater density appears to level some of the effects of voltage on resistance. Power increases more rapidly with resistance when samples are of a greater density. There is no "break" in the curves at excitation levels up to 100 volts in these samples.

4.5 CHARGE RELAXATION

Charge relaxation in M-9 propellants should be extremely rapid as long as the propellant is in contact with a grounded, conductive container. Resistivity is such that charges will not be retained. The highest value of resistivity measured was at -20°F at approximately 4 megohm cm (4×10^6 ohm-cm). Self generation of charge in grounded conductive containers would be difficult to the extent that appreciable energy could be stored.

4.6 SENSITIVITY TO INITIATION

M-9 propellant requires approximately 1.8 joules to be fired under conditions used in these tests. While firing is actually a difficult condition to define, it is felt that consumption of propellant, case

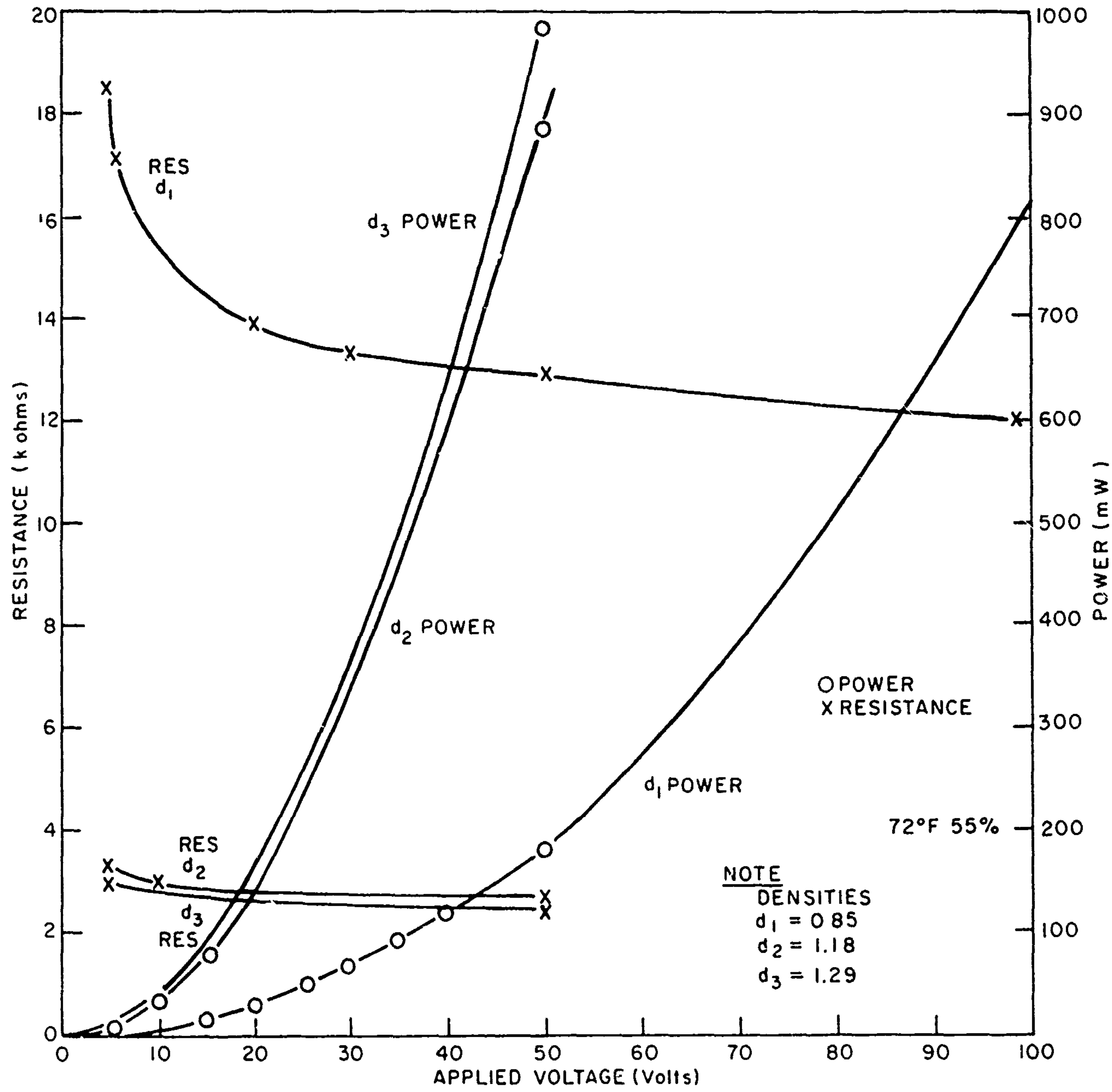


Figure 4-7. Resistance of and Power Delivered to M-9 Propellant with Potential - .006 Web

cracking, sharp report and light output are adequate. Other investigators have reported firing energies of .9 joules for M-9 propellant in an unconfined state. Good mixing with air could cause a propellant response at lower energy levels.

Size of the grain is important in governing response. Grains that were shaved to a very fine consistency and then exposed to an electric discharge fragmented containers, however the input energy required to accomplish this fete was about 3 to 4 joules.

Photography of the propellant simultaneous with pulse applications indicates that the propellant grains glow as energy is applied. The plasma appears to be that of burning propellant. The light output persists after removal of the electrical excitation for up to tens of microseconds. Further evidence that some reaction has occurred was observed in the appearance of the residual propellant. Exposures of 15 kV or more resulted in loss of graphite coating and an apparent small loss in grain size. After such exposure, the grains became clear and more polished. In no case, except for the finely shaved grains did a rapid reaction, disintegration of case, loud crack and complete disappearance of propellant occur.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 PLANT OPERATIONS

As a result of our inspection of the Indiana Army Ammunition Plant, Charlestown, Indiana, and of the investigation reported here, we believe there is little reason to suspect static electricity as a threat to plant operations with the exceptions mentioned in 5.2 below.

The reasons are as follows:

(a) The sensitivity of M-9 propellant ranges from .9 to 4 joules depending upon measuring conditions.

(b) Humans and other objects of similar size are limited in the amount of energy that they can accumulate, store and deliver. Human potential for delivering an energy burst is about 80 ampers for a period of 100 nanoseconds delivered at about 40 Kv. The energy content of this pulse is less than .32 joules.

(c) Normal operations preclude static events of this nature due to conductive footware and adequate grounding of machinery and nearby objects. (note exceptions in 5.2, 5.3)

5.2 QUESTIONABLE AND UNKNOWN AREAS

Propellant solids of the sizes investigated are believed to be safe from static electricity of the magnitude deliverable from humans or human-sized objects. There are two distinct areas that are believed to be questionable and in need of further investigation.

The first is in dusting or chipping of propellant. There is no reason to believe that the propellant does generate dust; the material appears to be too tough. In no instance did we observe dust from the propellant in plant operations. Some graphite was in evidence on chutes and in areas where propellant was moved. This graphite coating should be an asset rather than a liability.

There is evidence that fine powders are more subject to initiation than propellant grains. The air mix is better. A search of powdering of propellant in the plant and more detailed knowledge of what such dust would do under electrostatic discharge would be productive even if negative.

The second area which is questionable rests in the gas or vapor stage of the propellant. That such vapors or gases are present is clear from odors in the plant. Odors from freshly opened drums and storage containers can be sensed with the nose, indicating the presence of chemical products that are most likely reactive to sparks. What needs to be answered is:

(1) Are such vapors and gases reactive to electrical stimulus?

(2) If they are reactive, how much electrical energy is required?

(3) Can such vapors, if initiated, result in ignition of propellants?

5.3 ACCUMULATION OF CHARGE

Bagging operations - where propellants are weighed, injected into a bag and the bag sealed - and the hopper room - where drums are dispersed into smaller containers - are probably one of the areas of highest charge accumulation.[6]

In plant measurements revealed up to 22,600 volts on the propellant while pouring 150-lb containers in the hopper room. In this state, the potential is extremely high. The reason for the high potential is a greatly reduced capacitance in the isolated particles. By charge conservation (Q=VC) when capacitance is reduced, potential must increase. The energies present in these operations must be small dispite large potentials. Considering particle size of M-9 .006 web propellant as about 1.5mm, the isolated capacitance of each particle is approximately .075 picofarads.

5.4 SUGGESTIONS FOR IN-PLANT TESTING OF ELECTROSTATIC EFFECTS

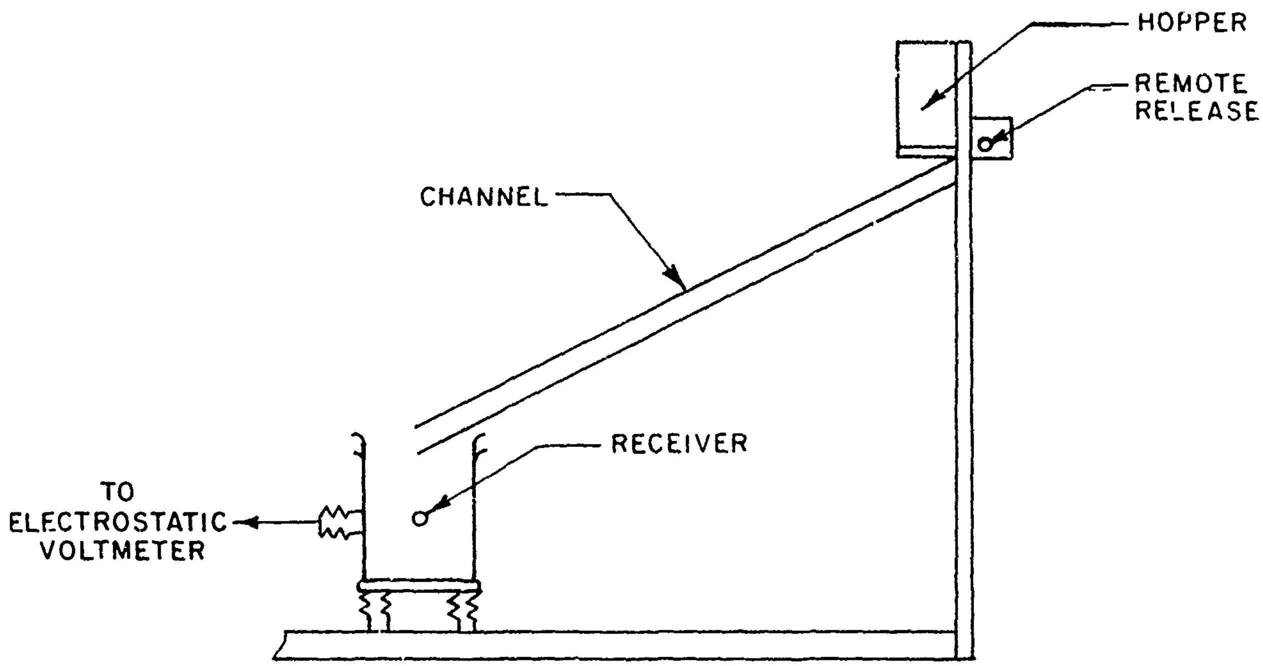
There is no reason to believe that a problem exists with electrostatic activation of M-9 propellant in the IAAP. The energy levels

required to bring about initiation of propellants is too high to be achieved under foreseeable circumstances; however, this does not mean that normal safety precautions can be abandoned. The unknowns mentioned earlier in Section 5 should encourage continuation of these precautions.

In addition, a simple check plan for electrostatic charge production may be in order. Several ways of doing this are available:

(1) *Read the relative humidity.* It appeared from this work that humidity lowers the resistance of the propellant. From earlier measurements at IAAP charges are produced or accumulated at a much lower rate when humidity is higher. The lower the humidity, the more potential problems from electrostatic energy.

(2) *Test the propellant.* Run propellant samples through an apparatus similar to the one shown in Figure 5-1. Samples could be taken from the line at regular intervals and run through the apparatus. The voltage on the electrostatic voltmeter should be a direct measure of the electrostatic hazard level.



1. Hopper Contains Propellant
2. Channel is Made from on Lines with Contact Material (from operation)
3. Receive is Metal Beaker on Insulation Platform

Gravity Feed System for Propellant Evaluation

Figure 5-1. Suggested Test for Electrostatic Hazard in Plant

6. REFERENCES

(1) Warshall, Theodore, Electrostatic Sensitivity of M9 Propellant at Indiana Army Ammunition Plant, Picatinny Arsenal Technical Report 4626, Feb 1974.

(2) TM 9-1910, Military Explosives, Department of the Army Technical Manual, April 1955.

(3) ORDP 20-177, Properties of Explosives of Military Interest, Ordance Design Engineering Handbook, May 1960.

(4) Ibid (1), p. 31.

(5) Tucker, J. J., Spark Initiation Requirements of a Secondary Explosive, Annals of the New York Academy of Sciences, Vol. 52 A-11, Oct. 1968, p. 643.

(6) Ibid (1), p. 5.

F-C3854

Appendix

A

VISIT REPORT TO INDIANA ARMY AMMUNITION PLANT -
CHARLESTOWN, INDIANA

THE FRANKLIN INSTITUTE RESEARCH LABORATORIES

April 11, 1974

TRIP REPORT

Persons Visiting: C. T. Davey
P. F. Mohrbach
Theodore Warshall
(Picatinny Arsenal)

Dates of Visit: April 3 and 4, 1974

Project: 12G-C3854-91

Visit to: Indiana Army Ammunition Plant
Charlestown, Indiana

Persons Visited: Mr. J. Hock
Superintendent of Safety for ICI American, Inc.
(Runs plant) Area Code 812 282-8961
Captain Sanderson
Mr. Brown

Discussion:

The plant is a joint venture and the officer that we met was Captain Sanderson. Out contact with Mr. Brown who is a Civil Service employee. We signed in, got our clearances, our badges, special clothing, including leg stats and cotton lab coats that were flameproof, hats and safety glasses, as needed. Our escort was Mr. H. M. Rice. He was instructed to take us wherever we wanted to go and he did a good job of doing just that.

We first visited a black powder pilot plant, Building 750-1. The person present and knowledgeable was L. D. Warf. This plant has the objective of a pilot plant operation for the manufacture of black powder. It is divided into several buildings (several parts). The first is a jet mill which takes the incoming components - - the nitrate, sulphur, and the charcoal and mixes it in this jet mill. From this mill, which produces a cyclone effect, the material is fed from a hopper, through a vibrator, into the jet mill and out. The cyclone collects and eliminates the dust, carries it off on the top of the cyclone. The finished product comes off the bottom. The next step is a dry mill in which 3% moisture is added by weight in a tumbler operation. There is also a trip-back

operation. It turned out, it was manufactured by Unitrack of Ontario, Canada. This operation is being used to check for dust production in black powder processing. This information we have requested from the Indiana plant, and information should be forthcoming to P. F. Mohrbach on this in more detail. The jet mill produces 11 micron particle sizes and from there the particulates are pressed into 1/4 lb. cakes. These cakes are class I, unglazed and about 1/3" thick and 4" in diameter. These are subsequently broken and vibrated through a screen of 4 to 8 mesh. Formerly, these black powders were manufactured by du Pont but currently they are being manufactured in Norway, Italy and Scotland, I believe. Here a correction is made for pressure versus specific gravity. Another operation involves an Abbe dryer and in this, hot or cold water or steam can be used in order to produce the desired result. This operation reduces rough edges as particles are ground with 10% by weight of graphite. This polishes the particles. This ends the black powder phase and this is kind of a side issue but it appears to be a very interesting one which may well develop into something of interest to this program.

Our main interest was in the 88 mm mortar propellant, the M-9 propellant. The propellant is not manufactured at Indiana Army plant. It is brought in by commercial carrier from other sources; most probably from Radford Arsenal. It is supplied, certified to specifications, from other plants. It comes in 150 lb (nominal) fiberboard drums. There are two kinds; one type is a complete fiberboard drum, the other type has metal rims around each of the closed ends.

From there it goes to what is known as the powder transfer Building No. 4901. The foreman here is K. J. Wessel. We observed the operations in this plant where they dumped 150 lb. lots into a hopper and reduced these in size to workable packages containing 5 pounds of powder each. A single hopper is filled from the 150 lb. drums. From there it is hand-loaded into a flat disk-like container to the 5 pound level. A lid or pressure disk is placed over the open top of this cylindrical cardboard container. Next a cover is placed over the lid and from that point a piece of masking rape is placed over the lid to retain the propellant.

This operation is strictly manual. There is no automation at this time. On observing the pouring of the 150 lb. drum into the hopper, considerable odor was noted. The claim was that this vapor was nitroglycerin; we understand the propellant is 40% nitro.

At the next location, an assembly operation, they receive 500 lbs. of the 5 lb. containers mentioned previously. They have a hopper room into which four hoppers each containing a maximum of 5 lb of M-9 propellant is placed. This hopper room is the starting point for the propellant that is used. From this hopper room the propellant is moved through vibrated shoots or troughs to the filling operation. The filling machine has two outlets. Each charge is weighed out automatically and put into a bag manually. The bag is about an inch across and about 5 inches long. It is ultrasonically welded on two sides. The other side is folded so that it is continuous. It is sewn from the top and then the weight is rechecked. The bags have two holes near the open end. These are attached to a continuous belt machine which takes them to an ultrasonic welder. There is an inspection point to indicate whether any propellant is present in the area which is intended to be welded. If there is, the machine is stopped. If there isn't, it proceeds to be ultrasonically welded and rechecked for weight and subsequently sewn on the outisde of the weld for added strength. This completes the manufacture of the bags but there is still an inspection for seal quality. The completed bags are placed in small slots in an aluminum shutter arrangement. Then a vacuum is applied to them. They are then turned upside down. The good bags swell; if there is no le-' -e, they remain in the aluminum shutter tray when inverted. The bad ones fall out.

The welding operation in particular has been proven to be a hazardous one. For this operation, they have a Primex detection deluge system which applies a water deluge approximately 3 milliseconds after an explosion occurs. There have been several opportunities to check this system, during accidental initiations and it has worked well.

We also looked into loading line L-A under Helen Cress and here they were making primers for large caliber ammunition. All operations

were by hand. The black powder that we talked about previously is loaded into a small thin sock. This sock is contained in a combustible spit tube, a primer for a large caliber artillery round. This lot is experimental and it is being tried as a means of standarizing production. We then experienced some of the cyclone weather that was predominant in the newspapers in the Kentucky and Indiana area this date it was pritty wild.

The next day we went back to the plant and discussed more of the problems in detail with some of the personnel including Mr. Hill and Mr. J. Hawk, the Superintendent of Safety. We thanked the people for their courtesy in taking us on a tour of the area. We also discussed some of the information that we would like to get from operations that are underway. This included a report on the testing properties of the operations in the pilot plant for black powder. We also asked for reports I1399 which is from ITTRI, their report number S6289. It is called "Quantitative Hazards Analysis and Material Sensitivity for the Improved Black Powder Plant". This will probably be sent to us. The report should be forthcoming. It is a detailed report on the operations of a black powder plant. We also learned that other reports are available on static safety some of which were sent to Picatinny. Ted Warshall will look into the possibility of getting these reports for our use.

In summary, the ammunition plant appears to be quite safe. The one area in which previous accidents and continuing accidents have occurred is in the region where the ultrasonic seal is applied to the filled bags. This area is now protected with the Primex System and therefore is more or less immune to disasters of the order that were previously experienced. As far as static electricity goes, there are several regions in which it appears that static could be generated. One of them is wherever the propellant comes in contact with the other materials particularly with the fiber drums, with the shoots where they are separated, in the containing bags, and any where that these bags were given motion. From discussions with Mr. Wessel, it is apparent that such static generation has indeed occurred and yet even though the generation has occurred to

to the point where the particulates of propellants stuck together there has been no initiation.

C. T. Davey

CTD/pc

Appendix

B

MEASUREMENTS AND CALCULATIONS ON M-9 PROPELLANT

THE FRANKLIN INSTITUTE RESEARCH LABORATORIES

Resistance Measurements on .023 Web Propellant

Resistance measurements were made on a random sample of single propellant grains. Ten measurements indicated an average resistance of 3100 ohms with standard deviation of 822 ohms. Measurements were made in the long direction of the cylindrical grain. The grains were measured for length and diameter using a micrometer. Length was 0.5168cm and diameter 0.1650cm based on the average of ten measurements. Microscopic examination of the grains showed that the graphite coating was mainly on the outside dimension of the grain. The grain is actually a hollow cylinder. Probing resistance measurements on the inside of a sliced grain indicated no continuity on the inside portion of the grain.

Energy-Temperature Considerations

The coating on the propellant is graphite. Handbooks yield the following data for graphite: density or specific gravity 2.09 to 2.23, resistivity 1400×10^{-6} ohm cm, specific heat .201. With the resistance and dimensions determined above the thickness of the graphite coating on the grain can be estimated. Resistance is determined by

$$R = \rho \frac{l}{A} \tag{1}$$

where R - Resistance (ohms)

ρ - Resistivity (ohm cm)

l - length (cm)

A - Area (cm^2)

The area of the coating may be expressed by

$$A = \pi \, dt \tag{2}$$

where d is the grain diameter

t is the graphite thickness

Assuming a uniform graphite coating, the thickness may be obtained by combining (1) and (2)

$$t = \frac{\rho l}{R \pi d} \tag{3}$$

$$t = \frac{(1400 \times 10^{-6})\ (.517)}{3100 \times 3.14 \times .165}$$

$$\underline{t = 4.5 \times 10^{-7} \text{ cm}}$$

The graphite Volume (V) and Weight (M) are:

$$V = \pi d + 1 = 3.14 \times .165 \times 4.5 \times 10^{-7} \times .517 = \underline{1.21 \times 10^{-7}\ cm^3}$$

$$M = V \times \text{density} = 1.21 \times 2.26 \times 10^{-7} = \underline{2.72 \times 10^{-7}\ \text{grams}}$$

It is not likely that the graphite coating will respond to joule heating in a predictable manner; however, if we assume that it does, then temperature rise could be estimated with heat loss neglected as follows:

$$AT = \frac{W}{M \cdot Hs}$$

where

ΔT - is the temperature change °C

W - is the energy - calories

H_s - specific heat calories/gram/°C

$$\Delta T = \frac{1}{2.72 \times 10^{-7} \times .201} = 1.83 \times 10^{-7}$$

For 1 calorie the temperature rise is about 10^7 degrees. One joule of electrical energy is equivalent to 4.186×10^6 calories. Thus under idealized conditions, the temperature of a small mass of graphite could be raised to very high temperature by electrical currents.